DECAY STUDIES IN WOODEN BOATS AND SHIPS

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Report Under NPO 15475 and NPO 19826, NS 032,001

In Cooperation with the Bureau of Ships, Department of the Navy

SUMMARY

1. A sample of 550 small boats was examined. The boats represented various types, mostly built during World War II, and were located in different parts of the country. The worst decay was in the many boats now in storage. Boats in active status had less deterioration. Further storage decay can be readily prevented.

2. Decay was seen or found by superficial probing at one or more points in 34% of the motor whale boats examined, 48% of the motor boats, 65% of the motor launches, and 73% of the landing craft. If all members could have been exposed for examination, the proportion found with decay would have been larger. The severity of the infection varied greatly from boat to boat; in some it was negligible while in extreme cases half of the frames were infected. The labor cost of locating and replacing decayed members is high, particularly in landing craft, and it is impossible to detect all the incipient infections. Hulls once attacked by decay are in particular need of protection from moisture after repair.

3. The heaviest decay losses have been due to lack of protection from rain for boats stored on land. This can readily be provided by watertight roofs, either with moderate overhang or with partial side walls that permit air circulation. Shelters good for many years can be built at costs in the neighborhood of $1.00 per sq. ft. of the area to be covered, thus probably from 2 to 4% of the value of most of the hulls protected. Several designs have been found effective; the most urgent need, if the boats still repairable are to be saved, is to provide shelters as soon as possible.

4. Many of the boats on inactive ships are already well covered; current transfer of these to uncovered land storage is increasing the seriousness of the decay situation.

5. For both repair and new construction the procurement of domestic naturally durable woods is increasingly difficult, and evidence on decay resistance of tropical woods is insufficient. Hence more extensive use and thorough application of chemical wood preservatives are needed. There is more use of preservatives than formerly, but at most shipyards it is doubtful whether the present application of preservatives is thorough enough to compensate for the additional hazard created by the increased amount of sapwood in use. There are difficulties in the integration of preservative treatment with other operations, especially in small boat repair. Nevertheless there are numerous places where improvement would seem practicable.

6. Absence or inadequacy of ventilation in forepeak and stern compartments of the larger hulls creates an additional situation acutely in need of attention. This is particularly true in the recent AM and AMS construction.

7. A number of ships were examined during overhaul. Despite some conspicuous cases of early decay, wooden hulls have had a longer average life than is generally realized.

8. The most interesting development in the study was not the frequency of decay in boats stored in the open, or in the unventilated compartments of ships. It was rather in the soundness of the majority of the members of wooden hulls even where precautions against decay have received little attention. By use of the more durable woods where practicable, better protection against rain leakage, more ventilation, and more effective use of preservatives, the serviceable life of wooden boats and ships can be extended beyond anything known in the past. More specific recommendations are listed at the end of the report.

DECAY IN BOATS AND SHIPS

Report Under NPO 15475 and NPO 19826, NS 032,001 1/

This report brings together the more significant information of four reports submitted earlier (refs. a, b, c, d), and findings accumulated since their issue.

Factors Affecting Decay

In wooden hulls nearly all the deterioration that is not clearly mechanical or caused by borers is due to a group of specialized fungi. More than twenty different species of this group have been found growing in ship timbers (ref. j). The microscopic threads of the fungi grow through the wood and make it brash and low in shock resistance even before there is perceptible softening or visual sign of decay. However, brashness does not necessarily mean infection. If a piece is uniformly weak throughout, it usually means that the wood was weak to start with. Fruiting bodies are sometimes formed on the surface of the wood, which produce multitudes of the microscopic wind-carried spores that start new infections. One type of fruiting body is shown in Fig. 1.

The common decay fungi need air and moisture. They can not damage wood while it is air dry, or while it is entirely immersed in water. Wood in structures that have been kept dry shows no material weakening after centuries of service. The decay organisms do not like salt water; most decay is due to largely preventable absorption of rain or condensation water, and not to the water in which the craft floats.

Most decay fungi can work best between 70 and 85°, and slowly if at all at temperatures below 50°F. (ref. m). Ship timber that has a long life north of Cape Cod may not be sufficiently decay resistant for service in subtropical waters. Fungi remain dormant but alive for long periods in wood that is dry or at freezing temperatures, but are killed by high temperatures such as are used in most kiln-drying and glue-curing processes.

Damage can also result from battery acids and sometimes from long time contact with iron. These can usually be distinguished from decay by their localization. Galvanic damage to wood due to contact with two dissimilar metals in fasteners in the presence of salt, apparently need not be considered if care is taken to avoid serious galvanic damage to the fasteners themselves.

1/ Based on local examination by J. W. Clark, Carl Hartley, P. C. Lightle, P. V. Mook, C. S. Moses, Arthur S. Rhoads, Elmer R. Roth and G. Y. Young, and consultation with ship designers, builders, operators, repair men, inspectors, and wood technologists and preservers.

Rate of Decay in Ships

The most rapid decay has generally followed periods of hasty construction (ref. g, i), but the early decay in some ships and long life of others can only be partly explained on the basis of present knowledge.

Despite the often hasty construction, the average life of the ships of the U. S. sailing Navy, as obtainable from published compilations (refs. g, i, k), was longer than some suppose. There were 122 ships for which at least 5 years history after launching was available. Of the 28 of these that were broken up, 13 had lasted more than 20 years and 8 more than 30 years. Of those lost at sea, half had passed the age of 13 years. Of those captured or destroyed, half were more than 17 years old, and of those sold, half were more than 20 years old.

No similar survey is available for ships built in recent decades. At least one of the submarine chasers built during World War I that had been sold to fishermen was still good enough to return to Naval service in World War II. Two of these SC craft moored in fresh water between the wars required extensive replacement of sawn frames in ceiled sections of the bilge when 23 years old (ref. a, Fig. 1), but otherwise were in fair condition. A number of smaller World War I submarine chasers retained as training boats at the Naval Academy had developed serious decay in unventilated stern compartments by 1941.

In hulls built during World War II, there has been opportunity to examine four ships of the APc type, four PCS, two YTB (Figs. 2, 3), four YTL, one YAG, one TAKL, and four YMS, all 8 to 9 years old, and two MSB at the age of 6 years (Fig. 4) as well as three YP of unknown age. Of the tugs, the two YTB and three of the YTL were severely decayed, one in the bow (Fig. 2), one in both bow and stern, and the others so extensively decayed throghout as to cause their condemnation. Even in ships condemned because of decay, the major portion of the wood is still sound. Decay in a small proportion of the framing members may involve such heavy labor costs in replacements as to require survey. Repair costs due to decay in the least infected of the five, a 110-foot YTB, were reported to have averaged $10,000 per year of life, in addition to the service time lost during repeated repairs, and still not all of the obviously decayed wood has been removed. The fourth YTL, though in essentially fresh water service, showed no decay in the superficial examination which was all that could be made. The APc hulls showed much decay in forward bulwark stanchions and frameheads, knightheads and stems. In the types with frames hidden by ceiling, removal of the ceiling would undoubtedly have disclosed more decay than was seen. More details as to the decay of most of these ships were presented in references a and b.

In the YAG, TAKL, YMS and two of the PCS ships seen, the hulls had not been opened up in repair and very little decay was seen in the necessarily superficial examination. A 10-year-old PCS was found to have a decayed white oak stem and keelson, and decay in all the frames, plank and beams around a meat storage room which lacked adequate vapor barriers and air circulation on the warm face of the wall, resulting in excessive condensation. Another PCS that had been transferred to

another agency lost the upper part of its stem and adjacent members due to extensive decay. Most of the YMS that had been retained after World War II are understood to have been usable in 1950. The badly decayed ships were ones to which attention had been called because of the decay and can not be taken as a fair sample of the vessels of their age. Despite the insufficiency of the data at hand, it seems evident that the average life of World War II ships has been considerably more than the 7 years sometimes mentioned as average. It is evident, however, that during a period in which the railroads have trebled the life of ties in their tracks, there has been little, if any, increase in the service life of wooden ships Naval activities are now providing advance notice on wooden ships scheduled for overhaul, and it is hoped by an increased number of examinations to accumulate better information on decay development in them.

Amount of Decay in Small Boats

In an effort to estimate the decay present in small boats, individual records were made on 553 of different types and in different situations. The numbers of boats required to make a balanced sample of 12 different types and sizes were supplied by Code 373, and were followed as closely as proved practicable. Punts and wherries were seldom found in storage yards or in the larger repair shops, in which most of the examinations were made, and decay appears relatively unimportant in them, so only a few of these were examined. Because decay could be evaluated most readily during repair operations, proportionally larger numbers were examined of the types that were found undergoing repair. Seven Navy activities that store or repair small boats were visited on the Atlantic and Gulf Coasts, and five on the Pacific Coast, together with visits to private contractors doing construction or repair work on Navy small boats. In addition to the 553 boats on which individual record were made, hundreds of others were given more general examination, and repair men and their supervisors were freely consulted as to their experience.

Most of the data on the formal sample are summarized in Tables 1 and 2 and have bee previously discussed (refs. c, d). Some decay was found in 73% of the landing craft, 65% of the motor launches, 48% of the motor boats, 34% of the motor whale boats, only 8% of the punts and wherries, and 34% of the boats of other types. Fo all the boats other than punts and wherries, 54% of the sample examined showed dec There is undoubtedly more decay than was found in the examination. Even of the boats under repair the majority were not opened up sufficiently to expose all of the points at which infection is likely to be found and even where infected wood is exposed the decay often cannot be recognized in its earliest stage. Of the boat built during World War II, the number actually containing some active decay may well be above 75% of the total. The relatively low frequency of decay among the motor whale boats is partly due to the fact that they are smaller than most of the motor launches, thus having fewer members subject to the chance of infection. Punts were still better off, not only because of the small number of members but probably because they were commonly nested upside down, a practice that has been recommended for other types where stored without shelter.

Decayed frames (Figs. 5, 6, 10) were detected in 23% of the motor launches, 20% of the landing craft, and only 10% of the motor whale boats, but the average number of decayed frames per infected boat was 10, 7, and 7 respectively for the three types. The large differences between boats indicated by these figures reflect in part real differences, but are due in part to the fact that many of the boats were not opened up sufficiently for thorough examination. That there are nevertheless real and unexplainable differences between similar boats, is illustrated by two 20-foot motor boats seen on the same inactive ship, built by the same contractor at the same time, with consecutive hull numbers and equal proportions of red oak; one of these boats appeared entirely sound and the other was severely decayed throughout. The distribution of the decay fungus is shown in more detail in the following tabulation.

Number of boats having the indicated number of infected frames

	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
Motor launches	72	10	5	3	0	1	1	1	1	0
Landing craft	139	23	4	5	0	3	0	0	0	0
Motor whale boats	138	10	2	1	1	0	0	0	0	1

Decay in fenders was frequent but of less structural importance and relatively easy to detect. Plank under the fenders are frequently decayed (Fig. 7). Decay of keel assemblies such as appears in Fig. 10 is fortunately rare.

In landing craft the corner posts and headlogs that constitute the ramp framing are important members in which decay was frequently detected. Other members often decayed in landing craft but not listed separately in the tables are coamings, coaming clamps, gussets, bulkheads, floor boards and quarter badges. Some of the coamings are of sweetgum plywood, at least in the cores, and in these severe decay was seen. The Douglas fir plywood of which the decks were made is commonly so deteriorated as to require replacement; excessive checking is usual and definite decay of the wood is frequent, as is delamination. Delamination appeared in the majority of cases to be due to failure of the glue, but frequently also to partial decay of the wood; the placing of responsibility was often difficult. The decay in the mahogany plywood sides of the LCVP under the armor plate, and in the worst cases of the frames and chines where in contact with the decayed plywood, was perhaps the larges single item in the decay damage. It was so frequent in the East that it was found necessary to remove the armor plate and often all of the plywood if there was to be assurance that all badly weakened wood was removed. The LCVP "plank" decay reports in the Tables refer mainly to this plywood, though decay occurred also in the solid mahogany bottom plank of some of these boats, especially where covered by the oak scufferboard.

As observed in previous studies, decay was more frequent under metal fittings, at faying surfaces, and especially where end grain was exposed in joints, than at other places.

The percentages of boats that show decay at some point (Column 3 in Table 2) do not bring out the differences due to situation and cover as well as do the columns showing the frequency of decay in each kind of member separately. The drier bilges of the ML and MWB from inactive ships and their lower decay frequency than in the land-stored boats were obviously due to the fact that three-fourths of the inactive ship boats of these types examined had covers of some sort. In the landing craft on the inactive ships, the majority were not covered and the decay was more severe. The lower decay frequency in the boats on or fromactive ships is explainable as probably in part due to exposure to salt water, and still more to the fact that they had been more frequently repaired in the past. The superiority of the active over the land-stored category is obvious from Table 2, which agrees well with statements by repair-shop personnel. The difference is probably greater than the tabulated percentages indicate, since most of the active boats were seen during repair, while most of the land-stored could only be examined superficially as they lay on the yard and would have shown more decay had they also been examined during repair.

Differences which do not appear in the tables are those between stored boats in California and those on the East Coast. The annual rainfall at San Diego, Long Beach and Stockton averages 10 to 14 inches, against 40 to 50 inches on the East and Gulf Coasts. The combination of drier climate and some intensive effort in cleaning out the dirt and debris that hinder drainage has resulted in generally much drier bilges at the California stations. As would be expected, decay in this climate was distinctly less than in most locations. In LCVP hulls, decay in the framing and around the ramp and in the mahogany side plywood was much less prevalent than in the East. Ash thwarts and thwart knees of the motor launches, which were common points of decay in the motor launches in the East (Fig. 8), were reported as not ordinarily decayed in southern California. However, chines in the landing craft were too frequently decayed (Fig. 5 in the West as well as the East, especially at the low point near the engine compartment bulkhead.

To summarize the condition of the small boats, most repairs in 1947 were for mechanical breakage. Decay was still a minor matter. Mechanical damage is still the principal cause for repair in most of the boats on active ships. In land-stored boats, on the other hand, particularly in the East and in Texas, much decay has developed. These stored boats are fortunately not as bad as they look, their appearance being marred by peeled paint, and by decay or other deterioration of the relatively easily replaced ash and the deck plywood. There is nevertheless enough decay to make thorough repair expensive. Some of the contracts for LCVP repair in the East have exceeded $6,000 per boat, due largely to stripping down all of them to facilitate decay detection.

The boats on inactive ships consist really of two subgroups. Those that have been continuously under tight rain shelters are generally in good shape, while those tha have been poorly covered show as much decay as in land storage.

The practical question as to how many of the boats in unprotected storage are stil worth saving depends on other factors as well as the amount of decay, and can not be answered by the pathologist alone. Many of the boats listed as showing decay have it in only 2 or 3 members and can be easily fixed. However, the fact has to be considered that the more severely decayed boats are quite sure to still contain some active decay even after the most careful repair. Repaired hulls if dried and kept in sheltered storage should be serviceable whenever activated in the future, but in service should not be expected to last as long as a new boat.

Wood Quality and Decay

The best service records of wooden hulls in the past have been largely due to the natural decay resistance of the better shipbuilding woods, and the use of seasoned timber.

Difficulty in getting the best wood for shipbuilding is now new. Both in England and New England before the advent of the railroad, transportation difficulties hampered procurement and inland forests were scarcely accessible. Much of the early shipbuilding was in times of emergency, when it became necessary to use whatever unseasoned timber could be gotten quickly.

Teak, black locust (ref. s), greenheart, cypress, and most of the cedars are examples of high resistance, while the various mahoganies, white oaks, old growth hard pines, hackmatack and Douglas fir also have resistance in varying degrees (ref. v). The evidence now available indicates that the Philippine mahoganies now used in small boats and the African mahogany (Khaya) are generally less resistant than American mahogany (Swietenia spp.) (ref. y, ae, and unpublished tests by C. S. Moses). Resistance is mainly due to very slightly soluble chemicals present in the heartwood that are poisonous to the fungi. These protective extractives usually occur in largest quantity in the outer heartwood, but there is so little in the sapwood that for practical purposes it is considered to have no resistance. Under some conditions, steel fastenings operate chemically to break down the protective extractives; galvanizing prevents or delays this effect, and non-ferrous fasteners are not known to have it.

Hardness does not impart decay resistance; maple, birch and ash are decay susceptible. Where wood is exposed to intermittent wetting as by rain or temporary condensation, slowness in water absorption is important for long life. One of the reasons for preferring heartwood is its low permeability.

Decay-resistant wood is still needed except where there is to be really thorough impregnation of the wood with preservatives. In that case some of the less durable species are often better because they are more easily penetrated in treatment. With pressure treatment red oak, for example, can be expected to do better than

white. Ash takes treatment relatively well. However, spruce, included in some small boat specifications for stringers, sheer clamp and other members, is decay susceptible (refs. e, h, v, y), and takes treatment poorly (refs. n, p), thus making it a doubtful species for boat use.

Only a single Naval ship has been encountered in which such members as stems and frames are being pressure treated. The use of red oak instead of white oak, in both ships and boats, has therefore undoubtedly contributed to decay. In several ships and numerous small boats built during World War II, that were examined for oak species, the number of red oak frames and other structural members equalled or exceeded the white oak. Decay comparisons were possible in 5 ships (ref. a); these showed twice as much decay in the red oak as in the white, thus confirming the results of laboratory trials (refs. q, r) and the experience with posts and railway ties ashore. The use of heart white oak is not a positive guarantee of decay resistance. In parts of a hull in which infection is extremely heavy, practically all oak members, both red and white, can be affected, as in the YTB 224 illustrated in Fig. 3, though in such cases the white oak is usually less completely decayed. There are large differences between individual trees; wood from the poorest white oak trees is less resistant than from the best of the red oaks (ref. r). Nevertheless, the general inferiority of untreated red oak is undoubted.

The most conspicuous decay resulting from use of non-durable wood has been in ash as used in thwarts, thwart knees, forepeak decks, seat boards and fenders (Fig. 7). Replacement of decayed ash, birch and maple with the same kind of wood without preservative impregnations invites repeated decay failure.

Untreated plywood has proved quite subject to decay. The heavy decay in plywood of gum and others of the less durable hardwoods was to be expected. Mahogany plywood also was frequently decayed, in some cases aggravated by the use of non-durable species in the core ply, but more often probably due to rain trapping construction detail in LCVP topsides that will be considered later. Untreated Douglas fir plywood appeared to have less than the moderate decay resistance attributed to solid heartwood of this species; this is believed due partly to the numerous checks in the plywood which led to ready absorption of water, and partly to the sapwood that is included in most fir plywood.

The current supply of domestic timber in U. S. construction appears to offer relatively little chance for improvement in the species used. Douglas fir is the only softwood of which quantities of large all-heart framing timbers can be obtained, since the virtual disappearance of the virgin stands of southern pine. Procurement of first quality oak is not easy. Only part of the AMS and small-boat builders have obtained all white oak for bent frames; others might get a larger proportion of white oak if inspectors were supplied with the indicators for distinguishing it from red oak (ref. a, Appendix II, and ref. t). The more susceptible red oak is being used to a particularly large extent in small boat repair. Frequently Navy

boat shops have felt obliged to use the mixed oak procured for them. Fortunately, nearly all of the laminating oak in new construction has been of the white oak group. Of 1,300 boards examined in 1953 from laminators in four different regions, all but three pieces were white oak, continuing the good record of the 2,200 pieces examined previously (ref. a). An illustration of effective use of decay resistance is supplied by a mine sweeper builder who used the highly resistant yellow Alaskan cedar for the high-decay-risk sills of the deck house.

Tropical woods not yet employed in shipbuilding present an opportunity for obtaining more decay-resistant material, and warrant intensive study (refs. ae, af, ah). Information on durability of a considerable number of species from tropical America is available (refs. z, aa, ab), but for most of these wider sampling and trial with more test fungi are needed for final evaluation. Woods from other parts of the world also deserve further study as well as five commercial North American oaks not yet tested.

The chance of early decay is decidedly higher, especially in the heavier members, if the wood contains much more than 30% moisture after it is painted. There is not only this direct effect of high moisture to be considered, but an indirect effect. Wood that contains much more moisture when installed than it will have in service may shrink excessively and the resultant seam opening increases the likelihood of subsequent seepage of rain into the structure. Philippine mahogany (red lauan) lumber was used by one builder when so moist that seams opened up badly by the time it dried to 17%.

The worst wood that goes into ships is of course that which is both too moist and already infected with decay. At one shipyard oak knees for AMS construction had obviously heart rot originating in the standing tree, which was being partly dug out and replaced with fitted plugs after a necessarily inadequate effort to disinfect the incipient decay zone that remained. In two of these ships at other yards, stems were being used which contained suspicious discolored zones. Lumber shipped green, or stored on the ground or without cover, too often becomes infected. Recognition of early stages of decay is difficult. Symptoms are discussed later in the section on repair.

Laminated wood has the advantage over large solid timbers in being dry and free from infection before it goes into a hull, but there is no reason to expect it to differ materially from solid wood of the same species in resistance to later decay infection, except as it sometimes is less resistant due to higher proportion of sapwood, a subject discussed in the following section.

Use of sapwood

The greatest question mark on the woods now in use concerns the large amount of sapwood that is going into construction without preservative impregnation. The high decay susceptibility of sapwood of all species is a matter of common knowledge Even the sapwood of the Atlantic Coast white cedar, which appears somewhat less

susceptible than most sapwood, decayed four times as fast as the heartwood of the same species in the single laboratory experiment in which it has been included (ref. e). Since cedar is used mainly for hull planking, in which the decay hazard is relatively low, the frequent inclusion of sapwood of this species is less unfortunate than of most other species, but is nevertheless undesirable unless effectively treated.

Unlimited use of sapwood is apparently allowed in the pine stringers of the 26' motor whale boat, in which only brush or dip preservative treatment has been required. This is the type of case in which it is more practicable and effective to improve the preservative treatment than to attempt to obtain all heartwood.

With oak, solid wood construction was superior to laminated in one respect: that sapwood in the heavier members occurred only on edges and was commonly worked out in shaping. In laminated oak, there is more sapwood and too frequently it extends nearly or quite to the center of the timber. (Table 3.) The amount of sapwood found earlier in laminating oak at one of the shipyards was illustrated photographically (ref. a, Fig. 2). In 1953 studies, sample cross sections of 240 laminated oak units were examined, containing an average of 10 laminae each. The products of six laminators were represented. Of these 240 units or members, 39% were all heart, and 34% had no interior face that showed more than a fourth sapwood in the cross sectional view. Eight percent of the members showed at least one entire interior face to be sapwood; there were more faces with 100% sapwood than with 50 to 99% sapwood, supporting previous observations (ref. a) that all-sap faces are easily mistaken for all-heart. The cross section containing the most sapwood is shown in Fig. 9. This wasan exceptional case, but the detailed results shown in Table 3 make it clear that despite the predominance of heartwood, there are still too many units in which decay could extend through susceptible sapwood nearly to the center of the member. For 533 laminae measured completely, an average of 5% of the faces were sapwood. The sapwood boards in general were scattered through the members at random. In some of the frames with sapwood, it was so generally confined to the edges that much of it would be removed in shaping or fairing, but in 21 of the first 49 members examined the sapwood penetrated halfway to the center in at least one lamina, and in 9 it reached the center; detailed distribution is shown in ref. b, Tables 1-4.

The frame shown in Fig. 9 is indication of insufficient inspection. However, a board can be within the 33% area limitation and still have sapwood across the entire width of the face at some one point. It would be safer to return to the original limit of the specification of 25% maximum sapwood area on any face, or perhaps better to make the 33% maximum apply to sapwood width at its widest point instead of the area of the whole piece. While there appears to be some difference between different laminators in the amount of sapwood they use, all of those whose products was adequately sampled had too many boards that were largely sapwood. The acceptance of all-sap boards might be lessened by providing inspectors with 0.1% methyl orange solution by which oak sapwood can be easily detected in doubtful
The methyl

orange has been found (ref. 1) to serve the same purpose as the less easily procured benzo yellow previously recommended (refs. a, t). The color reaction on the oak is the same (sapwood yellow and heartwood red).

In laminated frames, all of the laminations end in faying surfaces, either at the framehead or on the outer face of the frame. The end grain surfaces thus exposed in the joints are the most likely spots for decay to start. The previous advice (ref. a) is therefore repeated: that in laying up the laminations before end gluing, no boards that show sapwood on the exposed outboard end should be placed at the ends of laminations. It would also probably be desirable to keep sapwood out of the faying surfaces between the frames and the clamps or stringers. To accomplish this the boards in the inboard lamination should either be all heart, or any sapwood in this lamination be limited to its convex outboard face. The propose limitations on the placing of the sapwood would not appear to cause serious difficulty in laying up the boards before end gluing, since in the frame sections closel studied only a fifth of the board ends contained any sapwood. It is realized that if the proportion of boards with sapwood were to be much greater than a fifth, its entire exclusion from the end boards and from the inboard lamination might result in undesirable concentrations of sapwood elsewhere in the frames; but it is to be hoped that any such large amount of sapwood can be avoided. The effort by one laminator to avoid having any two pieces of sapwood in contact with each other is considered commendable.

In the case of solid bent frames of the AMS the amount of sapwood at points of high decay risk can be decreased by limiting pieces containing sapwood to the inner course of the 2-course frames. In all sizes of hulls, bending the frames with the sapwood on the concave (inboard) side should decrease the likelihood of decay. Some builders believe that this would increase breakages in bending, but timber engi neers consulted believe that with relatively mild curvatures there is little if any increase in difficulty as a result of bending with the rind side on the inner face of the bend. It is suggested that data on percentages of breaks in current construction could be collected that would settle this question.

Sapwood of most species takes preservative treatment much better than heartwood. In use ashore, pressure-treated sapwood is more decay-resistant than heartwood in all but the very most durable species. The same is probably true in marine construction.

Construction features affecting decay

Most decay in hulls used in salt water is due to joints or seams that admit and trap rain water. Rain tightness is not as easy to achieve in water craft as in land structures. A design feature that contributed somewhat to the decay hazard in the sailing Navy has now disappeared. This was the tumble home. During inactive

periods leakage through seams in the planking of the incurved topsides gave rainwater direct access to the frames and ceiling. This is strikingly evident in the high moisture content and extensive decay in ceiling and knees in the berth deck in the 95-year-old HARTFORD, limited to the midships portion of the hull in which the inward curvature of the topsides is pronounced.

Points have been noted at which hulls might be better protected against rain leakage. The most obvious is at the planksheer or water-ways. Frameheads are frequent and important locations of decay, and most of the moisture that makes it possible probably enters at imperfect seams. Working of the hull with moisture changes and mechanical stress makes water tightness difficult to maintain. The use of wooden bulwark stanchions which pass through the planksheer increases the difficulty by increasing the number of exposed joints between horizontal and vertical surfaces. Stopwaters, either cedar wedges or locust dowels driven tightly into joints between stanchions and the ends of the filler blocks that are placed between the stanchions, are helpful and are installed in some instances. Even these do not prevent infection of the stanchions at the deck line which may then work gradually down through the stanchion and into frames and beam ends if the stanchions are in contact with them. The elimination of stanchions through the weather deck in the recent AMS and MSB hulls has decreased the decay hazard in these ships. In the AM, a few through stanchions are still employed.

Even without through bulwark stanchions, there is difficulty in maintaining calking well enough to keep rainwater out of the frameheads, beams, and filler blocks. The upper surfaces of these can be protected by paying them liberally with fortified double-planking compound (so-called cement, Specification MIL-C-16245) before deck plank and planksheer are laid. The increasing use of this material on these faying surfaces as well as in the joints between frames and plank, stringers, etc., is considered beneficial as a barrier against both water and decay fungi. It is true that this hinders the "breathing" of the surfaces treated. However, the virtue of breathing construction is simply that it allows moisture to evaporate; if liquid water is kept out of the top of the frame and its outboard face, there will be little need for evaporation through those surfaces.

The plywood subdeck under the exposed parts of the main decks of the new minesweepers, with its upper face coated with bedding compound before the deck plank are laid, should protect the beams, and if carried far enough outboard the clamps and frame heads; but if the bedding compound layer is not thoroughly applied the result may be early decay of plywood and framing as illustrated in Fig. 4. The Dexolium used on some decks should help prevent decay if edge joints are tight and planksheer seams are covered.

Metal flashing has proved indispensable in building construction ashore to keep out rainwater at such points as the joints between chimney and roof, or between wall and door cap. It would seem potentially useful in boat construction. Some of the older construction is described as having the frameheads protected by a cap of sheet lead extending over the top and a short distance down the side. Stems

commonly have metal caps, which should turn down over the sides. In one ex PCS there was no cap at all at the time of examination, and the large checks that ran down into the stem undoubtedly supplied water for the decay which made the replacement of the stem necessary. The planksheer and waterways and the sills at the base of pilot house walls are points where the uncertain performance of seam calking might be advantageously reinforced by flashing.

Flashing would seem particularly applicable under the deck but over the frameheads and sheer clamp of the LCVP, coming out over the side plywood and armor plate (ref. f). This would serve to keep water out of the faying surfaces in this area. The bedding of these members in double-planking compound is helpful but it is scarcely possible to obtain a close enough fit of plywood sides to the armor plate to avoid voids between them that trap water and are too large to fill with cement. The use has been suggested of canvas with double planking cement as a partial flashing to keep water from the upper edge of the plywood; this should be beneficial but would need to be carried out under the fender and over the armor plate for positive results, with a rubbing strip to protect it. Rubber gaskets have also been proposed and appear to warrant consideration. A minor opportunity for possible improvement is noted in the chine area of the landing craft. The chine facing angle iron that protects the plywood edges sometimes probably traps water. At one of the repair activities it is replaced by two separate strips, one on the side and one on the bottom. These are closely in contact, but may give some opportunity for drainage of water that would be trapped if the angle iron were used. Most of the excess moisture in this area presumably comes from the inside.

An example of opportunity for better shedding of rain water by controlling slope of surfaces is in the rising (stringer) in the motor launch type. The upper surface of the rising is shown in the plans as horizontal, but with slight deformation of the hull it often develops an outboard slope. Rain water falling on it and on the filler blocks between frames is trapped against the plank and enters the joint between block and plank. Since the plank at this level has a bilge fender covering its outboard face, trapped water cannot evaporate readily, and decay of the plank in this strake is rather frequent (Fig. 7). An occasional boat has drains cut in the ends of the filler blocks, or was built with the upper surface of blocks and risers sloping inboard so as to shed rainwater safely into the bilge. Since the risings are regularly bevel-sawn, it would seem reasonably easy to increase the angle of the bevel to provide an inboard slope. The filler blocks could also be sloped inboard or provided with drain holes at each end.

In the LCVP type, the wedge filler between the ramp frame and the first vertical frame in a considerable number of the older boats and in some of the replacements in repair was cut off square at the top. Because of the shape of the hull, this gives its upper surface a strong outboard slope, trapping rain water against the skin and leading to decay in both the filler block and adjacent frames. It is particularly important to bevel the top of this block sharply inboard to let water run off.

Provision for drainage in the bilges is most important in boats that are out of the water part of the time. Drains are usually well located at the lowest point in the hull, but in the 50' utility boat the plans were understood to provide a drain on the port side only, making it possible for 4 inches of water to stand in the starboard side of the keel. Limbers are ordinarily provided through all frames; they are usually either too high to allow complete drainage or so small that they are too often clogged by dirt or paint flakes. Strength requirements presumably prevent much improvement in these. A clear case of expensive decay to which poor drainage contributed was in a YTL in which the spaces back of the frames next to the horn timber in the unventilated steering gear room had been partly filled with bitumastic. There were no limbers, and the bitumastic did not come up to the top of the frames to allow drainage over the frame. The lower edge of every frame in this area decayed and all had to be replaced. Use of bitumastic where carried high enough to allow drainage is not ordinarily considered objectionable, though in this case there was also some decay of inner face of plank under the bitumastic.

Ventilation

The importance of ventilation is the one point on which nearly everyone agrees but which rarely receives enough attention in practice. Ventilation is relatively inexpensive. If adequate, it keeps the larger proportion of the wood too dry to decay, and where decay has started it limits the rapid spread of the fungi over the surface that occurs where there is stagnant moist air.

The relatively recent substitution of bent frames without ceiling in the larger hulls (ref. o), in place of the traditional sawn frames and continuous ceiling, is regarded as a step toward decreased decay, in allowing better air circulation to the frames. In other respects, however, modern construction is less favorable to air circulation. The numerous water-tight bulkheads in modern ships and the built-in tanks, refrigerators, etc., limit free air movement inside the hull. An apparently unnecessary interference is in the flooring fillers between frames at the platform level in the crew's berthing and elsewhere in the larger minesweepers. These fillers completely cut off air circulation to the bilges. In some of the ships built during the previous decade the bays between frames at this level were left open, and dirt and trash were kept from falling into the openings by applying one or two strakes of baseboard or ceiling to the inner face of the frames, with a 1/4" mesh wire screen over the opening at the top of this baseboard. Perforated sheet metal was used in some cases in place of the screen, but the perforations in most cases were small and became clogged and ineffective after successive paint coats. Cases of severe decay have been observed in unventilated parts of the bilge in hulls that have been much in fresh water (ref. a, b).

In the AM 421 Class the air openings through the filler blocks between frameheads are small. Their enlargement appears desirable.

In addition to air circulation inside the hull compartments, there obviously must be interchange of air between the hull and the outside. This is more needed in modern construction than in the older types of ships, because of the vapor barriers now employed. The plank used in topside and deck construction had a slight "breathing" value in allowing slow escape of excess moisture vapor outward. In the topsides of the larger hulls, layers of double-planking compound in addition to the numerous layers of paint that accumulate inside and out, presumably reduce any such vapor escape to a minimum. In boats in which plywood is used in topside construction, the several glue lines tend to block vapor movement. Plywood is also now used in the minesweepers as a subdeck under the weather-deck planking, with a layer of double-planking compound on the plywood. The newer ships are thus much more vapor tight than ordinary buildings on land.

With this vapor-tight construction, if there is any water in the bilge or rain leakage from above, the air would soon become loaded with moisture. Air can carry only small amounts of moisture, and can be kept dry in a moist situation only if frequently changed. In a compartment containing 1,000 cu. ft. of space at a temperature of 60°F., evaporation of only 4 oz. of water would raise the relative humidity from the 50% that might have prevailed while the hatch was open, to more than the 80% at which condensation of water on cold surfaces would be expected, and the drying of any timber that had been wetted by rain leakage from above would be slow.

Moisture condensation in unventilated spaces occurs most conspicuously in cold weather, when the bilgewater is warmer than the air. It should then occur mainly on the lower face of the weatherdeck and the inner face of the top sides. Condensation as well as rain leakage thus contributes to the localization of most decay near the deck line. With adequate ventilation the moisture vapor is carried away before condensation takes place, or the wood on which it occurred dries again before decay has time to start. The forepeak and stern compartments which have been particularly frequent locations for decay have a relatively low ratio of air volume to area of outer surface. They may therefore need more frequent change of air than some other compartments, instead of less frequent change as is usually the case.

The MSBs now building have an effective-appearing cowl ventilator, and two gooseneck ventilators with 4 x 7" openings into the lazarettes. They should thus be safer from decay than the prototypes MSB 1 and MSB 2 in which the lazarette had no ventilators and showed serious decay in six years (Fig. 4). In the recently built AM and AMS hulls the entire lack of ventilators in the chain locker, steering gear room, and storage compartments near bow and stern present a serious decay hazard. Until chemical preservative treatment of stem, frames, beams, filler blocks, etc., is much farther developed than at present, dependence on occasional change of air by opening hatches can scarcely be considered sufficient safeguard. The efficiency of ordinary gooseneck ventilators is questionable, and operating personnel are reported as careless about opening ventilators after closure for rough weather. The situation is somewhat like that in the crawl spaces under basementless houses ashore, in which the difficulty in inducing

occupants to keep ordinary ventilators open during cold weather has proved insurmountable, and housing agencies have had to resort to other means in order to prevent decay. The difficulty inships might be partly remedied if a red metal signal were so attached to the ventilator that it would turn up conspicuously whenever the ventilator gate was closed. Ventilators are available with float valves which are automatically closed by water that starts to enter fromthe outside, and would never require manual closure. Another suggestion is that there be installed two deck vents per compartment with openings so small and protected that they could be constantly open, one of which would be connected with a duct extending to the bottom of the compartment and made into an efficient exhaust by building into it a small fan or a small heating unit. A difficulty with any constant ventilation system is that when the outside air is warm and moist it may actually add to the moisture in a cold hull. Such warm weather condensation is usually limited to the central and lower members, and in buildings any decay from it is negligible. However, it may be objectionable in its effect on gear stored in the compartments. If no efficient natural ventilation is practicable, the extension of the central mechanical ventilation system to the poorly ventilated compartments is proposed.

Ventilation also needs to be considered in some small boats. An example is the fuel tank compartment at the stern of the LCVP, in which decay has been frequently found. This compartment is ventilated only by two clam shell ventilators on deck, both of which are shown in the plans as facing forward. In the majority of the World War II LCVPs, both ventilators face forward, but there is also a considerable number in which both face aft. It would seem more effective to face one of these forward and the other aft, if they are to be the only ventilators. However, the effective opening of each is only about 7 square inches or a total of about 0.1 square foot for the two. Whatever their direction they are inadequate by the standards adopted for closed spaces in buildings ashore. It would seem better if feasible to leave both ventilators facing forward and add a transom ventilator near the top of the transom at each side. A still better way would be to make additional permanent openings through the top of the bulkhead for this compartment with a total net area of not less than 28 square inches, and turn both clam shells aft or substitute transom ventilators for them. The top of this bulkhead is well protected by the deck from rain or splash, and it is not water-tight, so that the suggested vents should do no harm. The manhole at present provided through the bulkhead into this compartment provides adequate ventilation when open, but it is normally closed except when the boat is in storage.

There is one situation in which air movement should be limited. In cold storage rooms the situation is the opposite of that usually found in other compartments. In refrigerators the cooling unit removes moisture from the inside air. This should keep the installation dry if the outside air is kept from contract with the cold wall. The refrigerator should not only be covered by insulating material but by an effective vapor barrier placed on the warm (outer) face of the insulation and of any framing members that pass through the insulation.

Preservative treated wood

Pressure treatment with preservative chemicals continues to be the most promising safeguard against decay where it can be used. It is employed generally in new ships for plywood, AM diagonalsheathing, chain-locker lining and worm sheathing; in the last named decay rarely occurs but protection is needed against marine borers. It is hoped that pilot tests now being conducted by other agencies will make practicable the early extension of pressure treatment to the stems, frames, and other structural members in which decay is more frequent.

Unfortunately there are limitations in the use of preservatives. Side penetration of oak and Douglas-fir heartwood is shallow, even in pressure treating. Preframing, cutting and boring of members before preservative treatment can be done to a greater extent than at present, as it is in other industries. It should be especially practicable in mass production of numerous small boats of the same type. But at least in the larger hulls it is difficult to avoid some cutting during assembly which will expose untreated wood at some of the most critical points; this can then be given only the superficial treatment that is practicable on the construction job. This on-the-job treatment can be made quite effective if carried through systematically, as will be discussed in the following section. Nevertheless, with the best treatment practicable the need for keeping fresh water out of the wood and for ventilation can not be ignored, and naturally decay-resistant woods continue to deserve consideration in hull construction.

Where it is not practicable to go at once to pressure treated wood, lumber with similar preservative retentions obtained by the vacuum process, even though less well penetrated, offers an opportunity for decided improvement over most present procedure. Vacuum equipment installed at major shipyards would make possible more efficient treatment of members after cutting to final size. Chambers can be built at relatively low cost that will accommodate members of sizes and shapes not adapted to pressure cylinders.

In small boats the recent progress to pressure treatment of plywood in new construction will certainly reduce decay damage in this material. The complaints of excessive checking following treatment with the water-borne salt preservatives are believed in the main to have been due to faulty drying after treatment. Retentions in fir plywood are reported to have been obtained as high as 40 lbs. of treating solution per cu. ft., which imply fairly complete penetration where such heavy treatments are practiced. Some further study by bioassay of the degree of protection given interior ply by preservative treatment at ordinary retentions is nevertheless desirable, particularly for the mahogany plywood in LCVP construction.

Non-pressure preservative treatment applied during new construction

The old preservative procedure was to "salt" ships. The more thorough treatments involved packing crushed rock salt between the frames from water line up to the frameheads, and boring holes in beams and other members which were to be periodically packed with salt. The salt packs were then to be flooded with brine. Where thoroughly done this was undoubtedly quite effective. Large quantities were required; the estimated amount for one of the 280-foot cargo vessels of World War I was 90 tons. Early in the present century the much more toxic creosote became more popular, but was sometimes considered objectionable and because it was usually applied only by brush was not very effective. Copper naphthenate, pentachlorophenol, and phenyl mercury oleate largely replaced it for use on boats. The last named is required in some specifications as a component of paint on fating surfaces, a probably advantageous use though not known to have experimental support. Double-planking cement to which pentachlorophenol has been added (Specification MIL-C-16245), has been shown to act as a barrier against spread of decay from one member to another. Borax was at one time proposed for use in the bilges, but has been found harmful to mahogany and oak under certain conditions (ref. ad). Fuel oil has been periodically sprayed on the inner hull surfaces by some tug and fishing boat owners. The belief in its effectiveness isapparently due to the relative lack of decay in the wood in engine rooms. This lower liability to decay is more likely due to the drying effect of the higher temperatures and better ventilation of engine rooms than to the oil. Most petroleums have little if any preservative value, but the less volatile may have water repellent effect.

The 48-hour immersion in preservative that has been required for red oak framing members in AMS construction is undoubtedly of value. Unfortunately, the majority of the builders and inspectors are not able to distinguish all red oak from white. The current move to provide inspectors with the indicators described in ref. t and Appendix II of ref. a for identifying oak should help insure the specified treatment for red oak frames.

In general the treatment of solid bent members to date is unsatisfactory. Bending oak is typically too moist for good penetration by oil treatments. In whale boats and in some of the AMS construction the frames are bent directly on the hull as they come from the steam box, providing no opportunity for subsequent immersion treatment unless the proposal sometimes advanced for immersing the entire hull of small boats in a large vat or vacuum chamber can be implemented. With laminated frames and with prefabricated sawn frames for V-bottom craft, the possibilities of treatment are less limited. The requirement in some of the more recent small-boat specifications that all wood members other than plywood be submersed for 24 hours in an oil-borne preservative after all shaping and boring has been completed signalizes a marked advance in protective construction. Although such treatments are definitely inferior to pressure treatment, soak treatment even much shorter than this has given some very good results. In an extensive experiment in a humid situation in southern Mississippi (ref. u), a 15-minute soak in the 5% pentachlorophenol solution without water repellent equivalent to Type B of Specification

MIL-P-00906C (SHIPS) was given to 30 pieces of pine sapwood, and a 30-minute soak to 114 pieces, in various types of assemblies designed to trap rain water. These have yet to show a single case of decay after 11 years. In identical assemblies without preservatives 75% of the pieces had failed after 5-1/2 years. Pine sapwood pieces with two brush coats or 3-minute dip showed indications of failure of occasional pieces at 6-1/2 years, and a fourth of those that had only brush coats showed decay infection at 11 years. Type A preservative (2% copper) used on a smaller number of pieces gave results at least as good as the Type B. It is true that conditions in this test, while intentionally made highly favorable to decay, were probably not quite as much so as in some parts of ships, and that most shipbuilding woods do not take treatment as well as the sap pine used in the experiment. Nevertheless, the degree of protection afforded by on-the-job treatment to this highly susceptible wood is very encouraging. They indicate that a 30-minute or even 15-minute soak is much better than brushing or short dipping. Confirmatory results were obtained on oak and fir heartwood in accelerated laboratory decay tests in which one of the features was weathering part of the untreated pieces both in sea water and fresh water (ref. w).

The water repellent added to the preservative under earlier specifications is needed for wood that is not to be painted, but is less necessary if paint is to be applied after treatment and subsequently maintained. Water repellents interfere with subsequent gluing and are under suspicion of interfering with the subsequent use of vinyl paints and of certain seam compounds. They have shown definite value in decreasing the pick-up of water through end grain surfaces in joints that are exposed to intermittent wetting, and may yet be found usable on boats in some situations, as they definitely have in the sash and door industry.

The use made of preservatives is much better at some shipbuilding activities than at others. The soak treatment of entire laminated-oak AM frames after fabrication at one yard is a unique example of thoroughness. At this activity there was also encountered the treatment of the ends of stems, and of frameheads after trimming to final height, by using cotton pads on stem and frameheads. These were soaked daily with the water repellent pentachlorophenol solution, and protected against excessive solvent evaporation by canvas covers over the pads. Sections 13 inches long trimmed from ends of two laminated fir stems that had had this treatment maintained for approximately a year during construction were subjected to laboratory study (ref. ac), indicating that even this extremely prolonged treatment results in only limited penetration. In the 11 laminae examined from different parts of the stems, the preservative had penetrated along the grain in sufficient quantity to prevent decay for the entire 13 inches in two of them, while in two there was no protection at all at 5-inch depth, and the other seven were intermediate between these extremes. This type of treatment for stem and frameheads, stern posts and transom stiffeners can evidently be very helpful, but even with the extremely

long treatment given the two stems studied it can not be counted on to protect a new surface exposed in later trimming to the final deck level. Such treatments are most effective if applied after the final trimming, even though it may then be possible to continue the treatment only a couple of days. As a substitute for maintaining a wet pad on the trimmed frameheads, they could be given a coat of one of the greases containing 5% penta which are now being developed by two of the preservative manufacturers. Where there has not been prolonged soaking or where some shaping and boring has been done afterwards, exposing untreated wood, additional preservative should be squirted or flooded with a brush into the joints, as is already being done by some builders. The treatment of bolt holes and of pilot holes for screws have varied from very thorough at some yards to little or practically none at others. Such treatment is probably less needed where the fastenings are of non-ferrous metals. There has been much more us of preservative in AM and AMS construction than in MSB.

Spraying has been used to apply preservative to wood in place. If done thoroughly, with a second spraying a few minutes after the first, with a nozzle set at an angle, it can reach places and particularly joints that are difficult to reach with a brush or squirt can. Because of fire hazard, spraying would have to be limited to operations out of doors, or if under roof, with abundant air circulation. At least if Type B preservative is sprayed, the operator would need to wear a respirator.

Repair operations

4(a) Removal of infected wood. In most of the repair activities observed, both by Naval establishments and by contractors, this is done conscientiously. It can rarely be completely successful. Not all surfaces can be reached for inspection. The complete stripping from landing craft of the side and transom plywood and of center gussets of bottom frames was regular practice at contract repair yards visited in the winter of 1952-1953. This permits close inspection of the most important faying surfaces, but such complete opening makes repair costs approach the cost of a new hull. Furthermore, there is no method known that can be used at a shipyard by which the earliest stages of decay can be certainly recognized even when exposed. Discolorations due to water, oil, iron stains, etc., increase the difficulty of locating incipient infections by color changes. Some fungi darken wood, while others in their early stages produce bleached spots sometimes with black zone lines. Probing with a sharpened screwdriver or icepick is usually the best way to detect decay, but decay fungi can be well established in the wood and cause considerable decrease in shock resistance before there is recognizable softening. Loss of toughness can sometimes be detected in wood that is not yet softened, by turning up a splinter. A long splinter usually means sound wood, while a square break of the wood turned up may mean either that it was brash to start with, or is in the early stage of decay. Another clue to decay infection is the presence of white strands of fungus threads sometimes found on faying surfaces that are exposed in removing one of the members. The safest procedure is to remove all wood that is perceptibly weakened or supporting fungus growth, and adjacent sound-appearing wood for a distance of at least two feet along the grain or three inches across the grain. Even if all infections that have caused material

weakening are found and removed there may remain some unrecognized active infections which if the wood is moist will develop later to the stage of destructive decay. Current practice where observed is usually to remove all obviously decayed wood, though occasionally some is missed; and to remove some adjacent wood, though frequently not enough to get out all of the infection. Leaving a little wood with incipient infection does no harm in non-stressed members, if they are to be continuously protected from wetting thereafter; but absolute guarantee of subsequent dryness is often impossible. The practice of replacing broken frames by driving a sister frame down beside the old one without removing it is sometimes unfortunately followed where the old frame contains evident decay infection. In some cases replacements are mainly limited to those called for on the job order or seen at the first inspection, even though some additional decay is located during the course of the work. On the other hand, some members that are probably sound are necessarily removed on suspicion. There would be less replacement of sound members if it were more generally understood that if the entire member seems brash or is uniformly discolored throughout the cause is usually something other than decay. In any large area of real decay there is usually easily recognized infection at some point.

(b) Preservative protection of new wood. Here the repair work observed has been definitely inferior to most of the new construction. It is undoubtedly more difficult to get workmen to apply preservative uniformly in a repair job, since replacement pieces are ordinarily shaped individually and installed before starting on the next piece, so if treated they must be handled before they have fully dried. Dipping vats scattered through a repair shop would create some fire hazard, and central treatment would involve more complication in a repair shop than in new construction. Colorless preservative has continued in use in some of the repair work, making it difficult to determine what wood has been missed in treating. Heavy brushing of old faying surfaces before installing the new pieces, and of the ends and edges of the new pieces before they go into place, needs more attention; these edges and ends need the most preservative treatment, and get the least. Working of preservatives into joints after assembly, by brush or squirt can, as done in some of the new construction, would take little additional time and give considerable added protection. If it were practicable to take boats out of the repair shop and spray them before painting, or still better to immerse them bodily in a large vat or a vacuum chamber, they would be better prospects for future service. At one repair activity no preservative was used on landing craft; a directive requiring preservative treatment in repair of all standard boats was interpreted as not applying to landing craft. Pressure-treated plywood is quite as badly needed in repair work as in new construction, and was not being employed at the repair activities visited.

(c) Replacement with wood that will resist decay. There is probably more need for decay resistance in replacements than in new construction. The decay hazard is higher, partly because of the unrecognized incipient infections which may spread from old to new members and partly because of the less adequate preservative treatment. In repair shops visited at both Naval Shipyards and private contractors, much red oak has unfortunately been used. At one of the Naval Shipyards, of 400 oak replacement members examined at different times a third were red oak, and some repair contractors were using mainly red oak. The general instruction to make replacements withthe kind of wood originally employed often leads to the use of ash and birch or maple despite their high decay susceptibility. Ash takes treatment rather well, but unless it is given at least a 15-minute soak in preserative after shaping, the use of white oak or fir would be preferable when replacing thwarts, knees, capping, seats and motor launch forepeak decks.

(d) Facilitating drying. Most boats seen in repair had wet bilges when received. These dry on the surface while in the repair shop, but readings indicate that bottom frames are commonly still high in moisture content at the time they leave the shop. The best adjustment to this appears to be to delay painting as long as practicable, and to apply no paint below the floor boards. Surfaces not painted should get an additionalcoat of preservative, preferably containing water repellent. In the replacing of plywood facing on the bottom frames of LCVPs, the use of double-planking compound between frame and gusset hinders the drying of the frame, and is advised only for a zone at the upper 2 or 3 inches, where the wood is usually relatively dry and where the compound may help keep rain water out of the joint between frame and plywood. If double-planking compound is used on moist frames, with plywood and paint over that, drying will be so slow that any unrecognized incipient decay infections can be expected to continue to work for a long time. The nearest to an ideal procedure is that practiced at one Naval Station where boats were stripped and then dried under roof for some weeks before replacing the plywood.

Storage of small boats

The heaviest loss from decay, and the loss most easily prevented, has been in boats in open storage ashore. Shelter is practicularly needed for the more expensive craft such as picket boats, which are difficult to ventilate, and for landing craft, which after uncovered storage require expensive opening up and stripping of armor plate and plywood before it can be determined whether they are sound enough for issue. Any shelter that protects against rain but allows free circulation of air will prevent further decay after boats have had time to dry out, for as long a period as may be desired, and irrespective of the kind of wood, construction detail, or shortcomings in preservative treatment. In locations with frequent extremely heavy fog, partial side walls may prove desirable on shelters. Incipient infections already established will not continue active in the wood if it is kept dry, and after some years will die out. This is true even in humid climates. Rapid paint deterioration is also prevented by shelter (Figs. 11, 12). From the standpoint of decay avoidance there is no need to renew paint during rain-protected storage.

(a) Uncovered storage. Most of the boats seen in land storage had no protection. The resulting paint deterioration is illustrated in Figs. 6, 7 and 12. Drains are usually open, though not in all cases. Boats are not always placed properly on the cradle to bring the drain to the lowest point. Some motorboats have no provision for drainage at any point except by pumping. In landing craft the engine compartment particularly is commonly undrained, letting water accumulate abaft the bulkhead. In open storage, limbers and sometimes drains are sufficiently clogged with paint flakes, often reinforced with leaves and other debris, to keep from 2 inches to a foot of water standing in the bilges of many of the boats. In boats on ships, drainage is sometimes hindered by sand allowed to get into the boat during sand blasting. Pieces of loose equipment not infrequently left in the bilges of stored boats, especially life jackets, mattresses, rope and tarpaulins, trap water under them and increase the decay hazard. The shock-absorbing "puddings" suspended over the sheer plank of some types of boats also hold moisture and deteriorate themselves as well as holding moisture on the fender and plank, and should preferably be removed when storage begins. Doors and manholes in bulkheads are open and floorboards removed in a large part of the boats, and should be in all. Above the bilges the greater part of the wood is safely dry most of the time, but paint films are usually broken at joints, trapping rain water at enough critical points so that only the natural durability of much of the wood used has saved the boats from much more serious decay. Some punts have fortunately been inverted in storage, a practice that has been recommended for the smaller boats generally when shelters were not available. If boats must be stored without cover, it is best to place them pointing due north or east of north to give both port and starboard sides the drying effect of sun exposure during part of the day.

(b) Effect of covers. If rain is kept out of the boats, they remain safely dry. Wood under cover does not pick up enough moisture from freely circulating air to enable decay fungi to work. It is true that uncovered boats, like automobiles, accumulate much condensation moisture on their surfaces during clear nights, and while most of this evaporates during the day before it can be absorbed deeply into the wood, that which runs down the sides into joints may sometimes graadually build up dangerous moisture at the faying surfaces. Under cover, however, the heat loss by radiation is so decreased that condensation under a roof is normally negligible, even on nights when uncovered equipment is streaming with water. A single boat under a roof but without sidewalls may sometimes show some condensation on the sides or ends but side condensation is regularly much less than the condensation that occurs on the tops of uncovered objects. In boats stored close together, side condensation should be negligible because of reciprocal radiation. Electrometric moisture contents determined in boats that have been covered have been regularly low, except in cases that were reasonably explainable as errors due to salt content of the wood, which causes moisture meters to read too high. In some localities roofs would need to be wide enough to keep large amounts of snow from being blown into the boats.

(c) Shelters in use on small boats. Thirteen percent of the boats examined in land storage and 61% of those from inactive ships were known to have had covers of varying types (Tables 1 and 2); the actual number covered may have been larger in

the boats from the ships. On the inactive ships the covers were most commonly of roll roofing mounted on wood frames. Where the frames had tight sheathing and a moderately heavy grade of roofing was employed, the protection given was generally good. Where gaps of several inches were left between sheathing boards the roofing was often torn, in some cases admitting most of the rain and hindering its evaporation to such a degree as to be probably worse than no cover at all. Lack of sufficient slope aggravated the leakage in some cases. Some boats were stored in hangar decks in which they remained safely dry.

On land-stored boats canvas was the cover most commonly encountered. It was often old and torn, and generally not well enough supported or secured to prevent sagging and rain entry or to allow air circulation. The same errors in the use of canvas are nearly universal in private boat storage. Where a heavy canvas is properly used, it gives good protection. In the trial illustrated in Figs. 11 and 12 it was effective for 4 years, but by that time had numerous small holes due to mildew and needed replacement.

Other types of shelter seen on land were generally better than the canvas. These included wooden sheds covered with asphalt roofing, and sheet metal covers, some of which were supported on wood or steel posts and some on wood trusses that rested directly on the boats. A few covers were seen which covered only the cockpits. By discharging all of the rain onto the planksheer and transom these may cause as much decay as they prevent. A promising recent development is a sheathing and roll-roofing cover for LCVP's, on stringers that rest on the ramp and stern which automatically provide slope from the bow. Ingenious covers used included surplus plastic gun covers cut in half to make the two ends of the shelter, connected by iron pipe which supported canvas over the intervening portion, though allowing some leakage at the joint. At three activities, expansible sheds have been designed in unit sections, which thus can be used efficiently for boats of varying lengths. At one activity large sheds resembling the modern pole barn, approximately 85 feet wide, have been employed, in which roof sections are removable and boats can be placed by crane. In this and some of the other sheds seen, boats were stacked two or three high, with resulting economy of space. In a few cases boats were stored in inactive space in shop buildings.

(d) Transfer of covered boats to uncovered storage. It is understood that boats are being moved from inactive ships to land storage. Insofar as the boats moved are those that have been under effective cover on the ships, their transfer to land storage without simultaneous arrangement for cover in the new location accentuates the decay problem. In some cases it may be practicable to move the present shelter along with the boat.

(e) Considerations other than decay. Dry storage to prevent decay has been questioned on the ground that it would aggravate the opening of seams. To prevent this, water was maintained in the bilges of some boats for the first years of inactivation, but the practice now appears to be rare except for boats kept for emergency use. In these, salt water is sometimes used, and is much better than fresh water from the standpoint of decay avoidance; some of the modern more efficient fungicides added to bilge water should be better than salt. In general the opening of seams observed as a result of keeping bilges dry has been unimportant in the East and South, especially when there was minimum interference with air movement. In a usually unheated shop building at Norfolk and a somewhat heated building at Boston, seam opening and in some Norfolk cases the splitting of shaft logs was rather conspicuous (ref. c, Figs. 10 and 11) and will require recalking and some replacements in the boats most affected. In the dry climate of Stockton, in a shed in which the sides as well as the roof were tight, seam opening was considerable. There has also been somewhat more seam opening in hangar deck storage and in boats under shelters with side walls on inactive ships than in boats stored in the open on land, presumably because of more radiation from decks than from soil. In Bureau of Ships experiments on land-stored boats at Norfolk and Mare Island, covers that kept the hulls dry but without side walls caused practically no seam opening (ref. c, Fig. 6, and ref. x) and in the boats with dry bilges at Mare Island less extrusion of calking was reported than in those in which water was maintained in the bilges. All the observations have indicated that if there is sufficiently free air movement from the outside there is no need for humidity control in storage except in cases in which corrosion of metal is important or possibly in a very dry climate like that of Stockton. For protecting the boats from decay and paint failure without damage to seams, in most climates a mere roof without sidewalls is so effective that it would seem difficulty to justify anything more complicated or expensive.

(f) Design of shelters. The most essential ingredient in the success of a shelter in the present situation is time. Many boats now in storage, including those completed in 1945 and classified as "new", are sufficiently infected so that a little further delay in protecting them would put them out of the repairable class. A uniform design can presumably be developed that would be cheaper per year of life than any of the effective ones now in use. However, while this is being done, it would appear advisable to provide for the more valuable of the store boats, shelters of whatever type the local activities can construct with materials readily available. General requirements to be observed might include the following: that the shelter keep rain off the entire boat and not merely the cockpit; that roof sheathing be continuous instead of widely spaced; that asphalt roofing employed should weight at least 50 pounds per 108 sq. ft., preferably of the mineral-surfaced wide-selvage type; and that sidewalls if used should be partly open for air circulation, and the roof high enough to allow access to the boats. If in any locality observation should show that fogs frequently deposit so much water on boats under roofs that it runs into seams or joints, the upper part of the shelter would need to have sidewalls added. The use of snow fencing for side walls, and stacking boats one above the other to save space, are economies with which there is already experience. Poles for the pole-barn type can be readily purchased with either standard full length pressure creosote treatment or the hot-and-cold butt treatment. Cost records or estimates available for wooden-frame

shelters approximated $1.00 per square foot, and thus of the order of 2% to 4% of the value of the boats sheltered. Similar cost estimates have been furnished on sheds with aluminum roofs, supported either on creosoted poles or on demountable steel framework.

For short storage periods or as a stopgap until other shelter can be provided, covers of heavy treated canvas are satisfactory if supported by a frame that gives the canvas sufficient slope to prevent sagging and raises it 4 inches above the gunwales to allow air movement. Most reports have credited canvas with a shorter life than 4 years; the type of canvas in these cases was not learned. Canvas with a heavy coating of plastic (Spec. 52C44, Std. Stock Nos. 52-C-2250-5 and 52-C-2250-10) would presumably last longer. In terms of cost per year of use, the economcy of canvas is doubtful. The difficulty in assuring continued maintenance is a still more serious item against reliance on canvas covers for long time storage.

In some cases there has been decay in the supports of the shelter itself or in the cradles on which the boat rests. Under good shelters, there should be no need for preservative treatment of the roof framing, or of the cradles if they are supported on concrete bases without contact of the wood with the soil. Supporting posts or other wood in contact with the soil or set in concrete should be pressure treated. The same is true for wood that gets much rain or rain splash; if that is impracticable, it should be soaked overnight in an oil borne preservative after all cutting and shaping has been done.

Inactive ships

These present a special problem. Natural ventilation is less than during service, and mechanical ventilation is usually discontinued when ships are laid up. Deck seams are less well maintained against leakage. Furthermore the ships are commonly laid up in fresh water to escape shipworms, which results ultimately in increased chance for decay below water line. Southern stations are particularly hazardous locations because the temperature is high enough to allow decay fungi to work in winter as well as in summer. It is sometimes said that a year of inactivity is as bad as five years in service.

A primary need is increased ventilation. If dynamic dehumidification of which some trials are being made should prove practicable for wooden hulls, it would very materially improve the situation. In inactive status it may be possible to use rain proofing materials, particularly in the region of the planksheer, that will decrease water leakage from above. The best location for inactivation from the standpoint of decay avoidance would be in a cold climate, and in salt water if places can be found in the North where shipworms are not active. The addition to the bilge water of a powerful fungicide of low solubility, which would not be lost too quickly in pumping, would probably aid in protecting ships moored in fresh water. (ref. ad)

Recommendations

(a) Extension of laminated construction to all heavy members.

(b) Extension of pressure treatment with preservative to include frames, stems, beams and other critical members that do not receive it now. Laminated members to be treated before gluing, if practicable.

(c) Improvement of non-pressure treatment on the job, particularly in small boat repair.

(d) Where real impregnation with preservatives is not possible, continuation of effort to procure wood of decay-resistant species with a minimum of sapwood, and such placement of any sapwood used that there will be the least possible amount of it on faying surfaces.

(e) Further studies of decay resistance in promising tropical woods, each taken from enough sources to fairly represent the species as a whole.

(f) Improvements in construction detail for excluding rainwater, such as flashing and stopwaters.

(g) In repair, extension where practicable of the excellent procedure at one Naval Station, in which small boats after opening up are dried for some weeks under roof before making replacements and repainting.

(h) Omission or postponement of interior hull painting for wood that is high in moisture content.

(i) Adequate ventilation for all enclosed spaces in hulls.

(j) Establishment of records on each hull of the materials and preservative methods used, to make possible their ultimate evaluation.

(k) For small boats in storage, better drainage and low-cost shelters that will exclude rain but allow free air movement; inverting for the smaller types when shelters can not be provided. The effectiveness of several different types of cover has been demonstrated. To stop decay before more of the stored boats pass the repairable stage, prompt action is needed.

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TABLE 1. NUMBER OF SMALL BOATS EXAMINED IN DECAY STUDY

Type and length	Total	With decay	Cov-ered	Number of boats showing decay in: Skin (plank or plywood)	Frames	Fenders or rails	Stringers, shelf, or rising	Thwart or thwart knees	Deck	Other 1/
Motor boat 40'	6	3	0	3	1	1	0	-	0	3
35'	4	2	1	0	0	0	0	-	0	2
20'	13	6	4	1	3	0	0	-	0	6
Motor launch 50'	11	11	0	5	4	4	6	11	4	7
40'	31	19	7	6	12	5	7	15	8	12
36'	25	14	11	2	3	4	2	10	8	11
30'	20	11	5	0	1	4	1	6	2	5
26'	9	7	1	1	2	4	0	4	4	7
Motor whale boat 26'	152	51	45	6	12	17	5	-	17	41
Wherries 12' & 16'	5	3	0	3	1	2	-	-	-	0
Punt 14'	33	0	16	0	0	0	-	-	-	0

Type and length	Total	With decay	Cov-ered	Skin (plank or plywood)	Frames	Fenders or rails	Sheer batten	Chine	Headlog	Corner post	Transom	Other 1/
LCVP 36'	132	100	16	67	34	26	35	47	29	47	22	80
LCP(R) 36'	33	24	9	16	3	6	3	10	3	13	2	23
LCPL	20	11	4	4	2	0	3	3	-	0	2	7
PRB 35'	16	9	2	2	4	1	2	4	-	3	0	8
Plane pers. 24'	21	5	6	1	1	1	1	1	-	1	1	5
Other	19	8	6	0	3	2	0	0	-	-	0	8
Total	550	284										

1/ "Other" decay included: vehicle track in 30 LCVP; keel in 1 MB, 2MWB, 4ML, 1 LCVP, 2 PRB; keelson in 1 MB, 3 ML, 1 PRB, 1 Plane Pers., clamps in 6 MWB; stem in 1 MB, 1 ML, Plane pers.

TABLE 2. DECAY IN SMALL BOATS IN DIFFERENT SITUATIONS

Type and source	Number studied	% with decay	% covered 1/	Skin (plank) or plywood	Frames	Fenders or rails	Stringers, shelf, or rising	Thwarts or thwart knees	Deck	Other
				Percent of boats showing decay in						
Motor whale boats										
Land storage	79	33	11	7	9	15	4	-	9	26
Inactive ships	52	29	71	2	6	8	2	-	15	27
Active ships	21	48	-	14	9	5	5	-	14	33
Motor launches										
Land storage	55	75	16	20	20	27	13	62	38	53
Inactive ships	19	53	79	16	26	11	21	32	16	37
Active ships	20	50	-	15	30	15	30	30	10	30

Type and source	Number studied	% with decay	% covered 1/	Skin (plank) or plywood	Frames	Fenders or rails	Sheer batten	Chine	Head log	Corner post	Transom	Other
Landing craft												
Land storage	92	70	14	38	28	19	25	30	16	30	12	58
Inactive ships	43	91	40	72	14	28	23	58	26	60	12	79
Active ships	43	67	-	51	19	14	21	19	14	26	5	54

1/ History of cover often uncertain; most boats from active ships have been uncovered; some boats now uncovered had been covered previously.

Table 3

Sapwood in laminated oak members examined in 1953

	Number of units with the indicated width of sapwood on the worst interior face.					
Unit	0%	1-25%	26-50%	51-75%	76-99%	100%
Transom	1	1	0	1	2	4
Frame	38	47	15	6	1	8
Stem	24	15	12	4	0	3
Stern post	20	4	5	0	1	2
"Deadwood"	7	3	0	0	0	0
Keel	3	11	0	0	0	2
Total	93	81	32	11	4	19

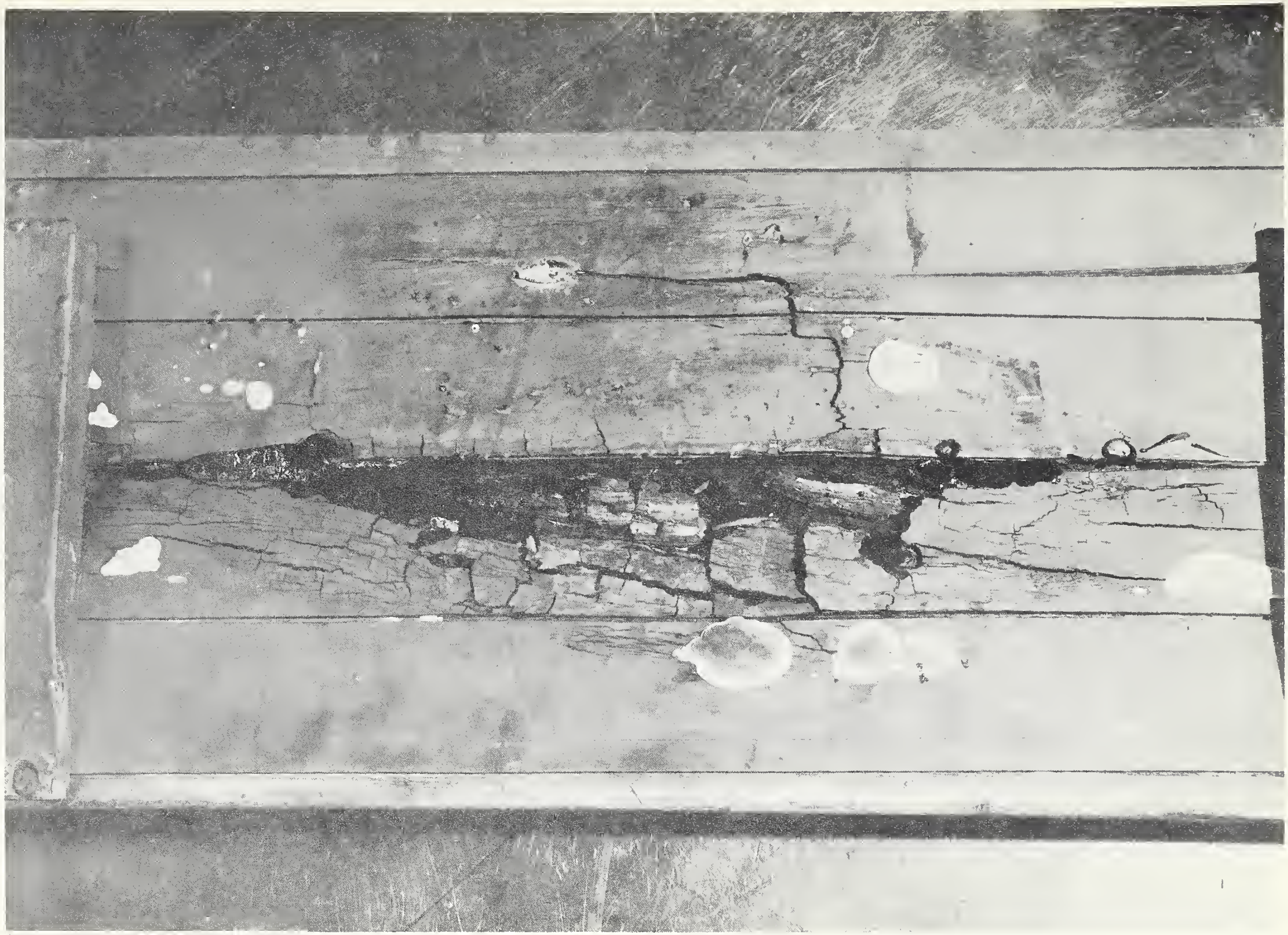

Fig. 1. Decay in ash locker cover, showing the spore-producing mats of the decay fungus.

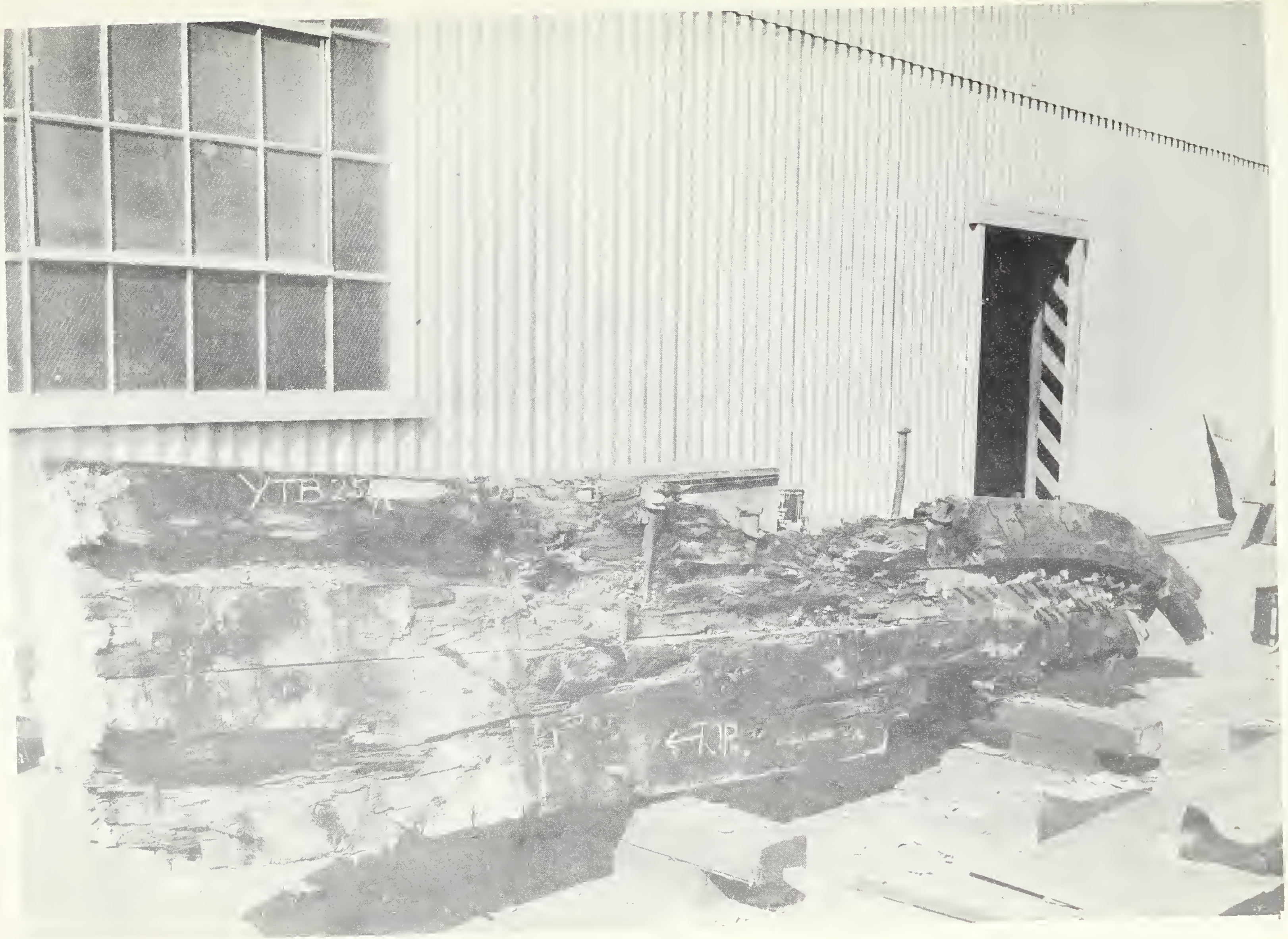

Fig. 2. Decay in stem and apron removed from MENATONEN, YTB 254.

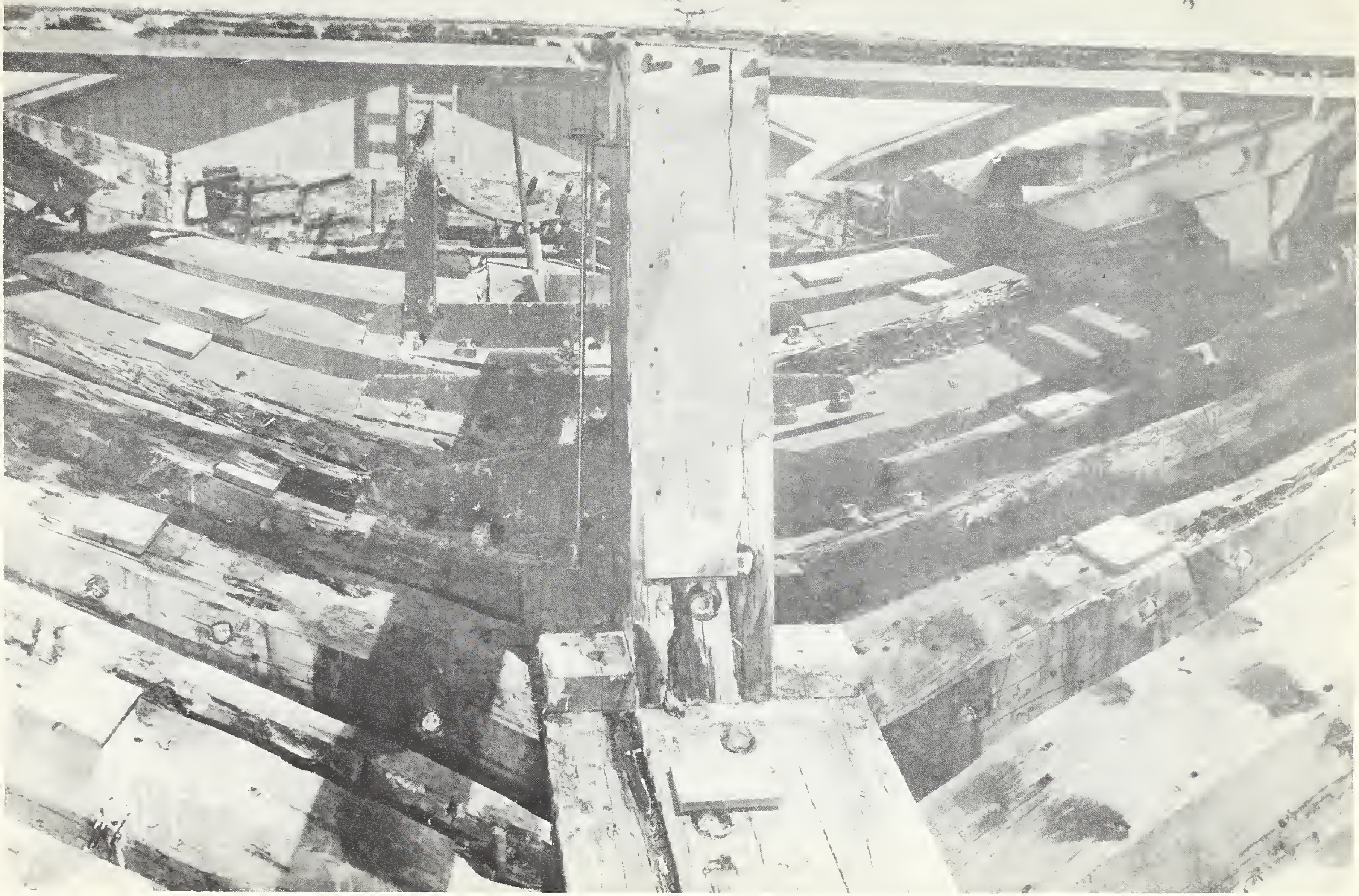

Fig. 3. View aft in YTB 224, nine years after construction. Decay in nearly all of the frames.

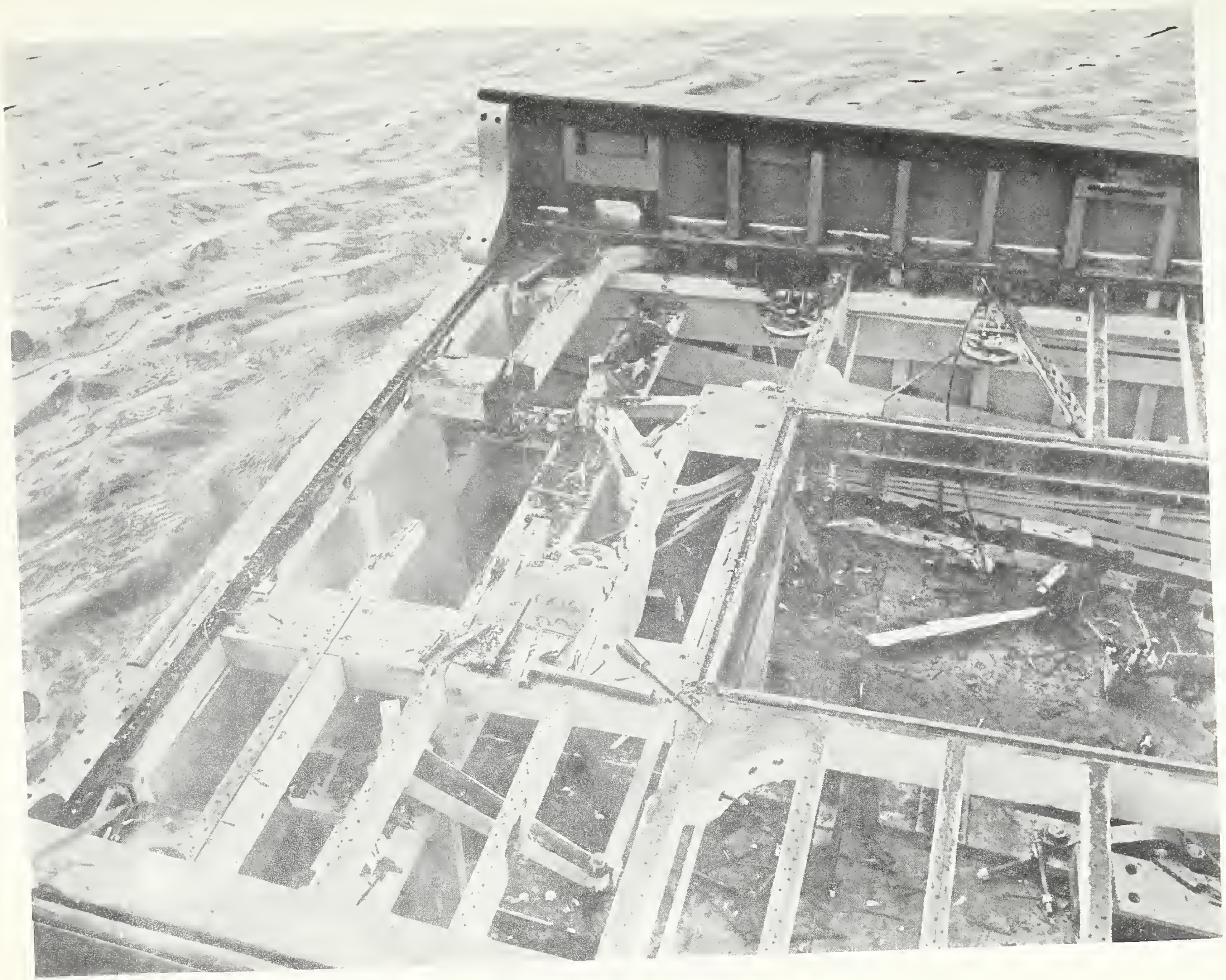

Fig. 4. Repairs required in unventilated lazarette of MSB-1, due to decay after six years in service. Present design fortunately does not include bulwark stanchions through the planksheer.

Fig. 5. Decay in chine and frame of LCVP revealed only by stripping off plywood hull planking.

Fig. 6. Decay in 40-foot motor launch in open storage. The right and middle frames are red oak, the left frame and butt block white oak.

Fig. 7. Decay in bilge fender and plank under it. Rain water is trapped between them, and also between the inboard face of this plank and the riser filler blocks.

Fig. 8. Decay of ash in plank, thwart and thwart knees of motor launch in which most of the oak was sound.

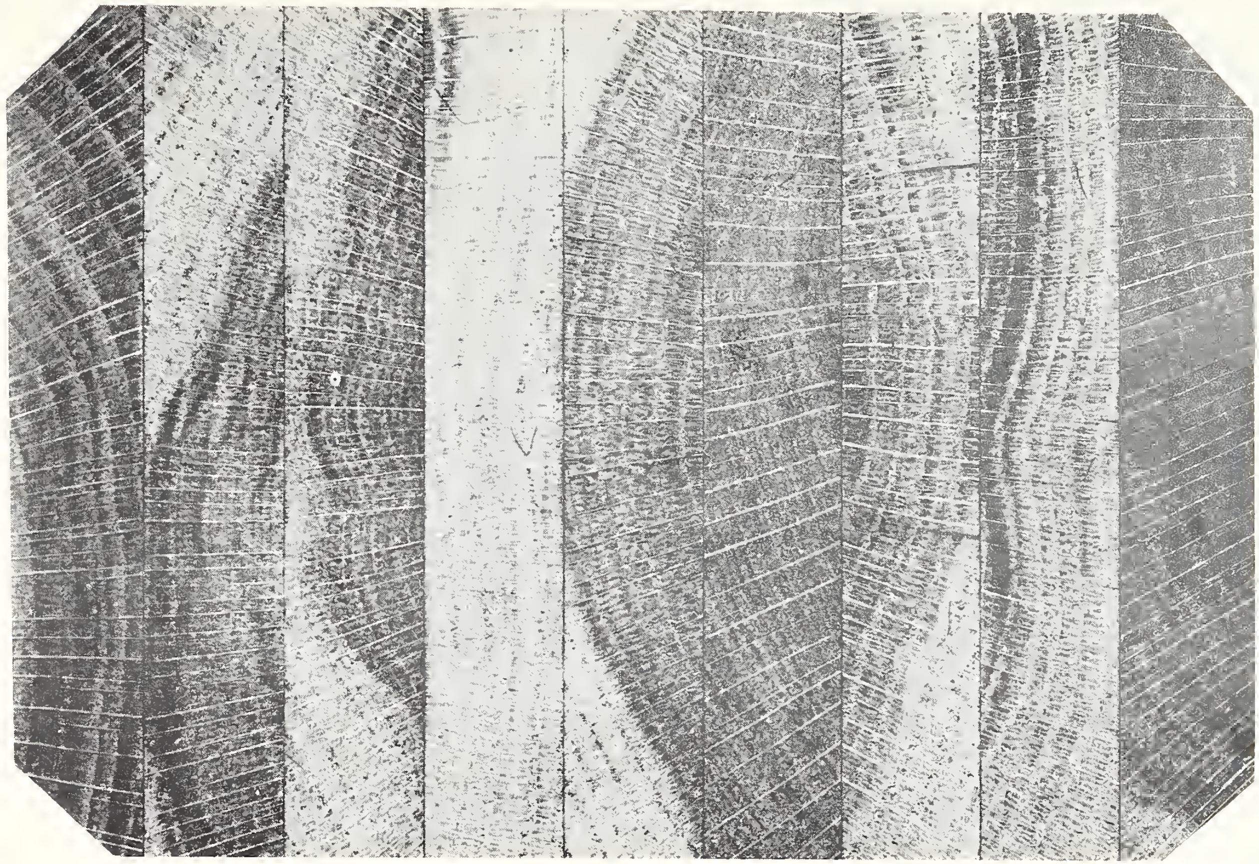

Fig. 9. Top of laminated oak frame, showing sapwood making up 35% of the cross sectional area.

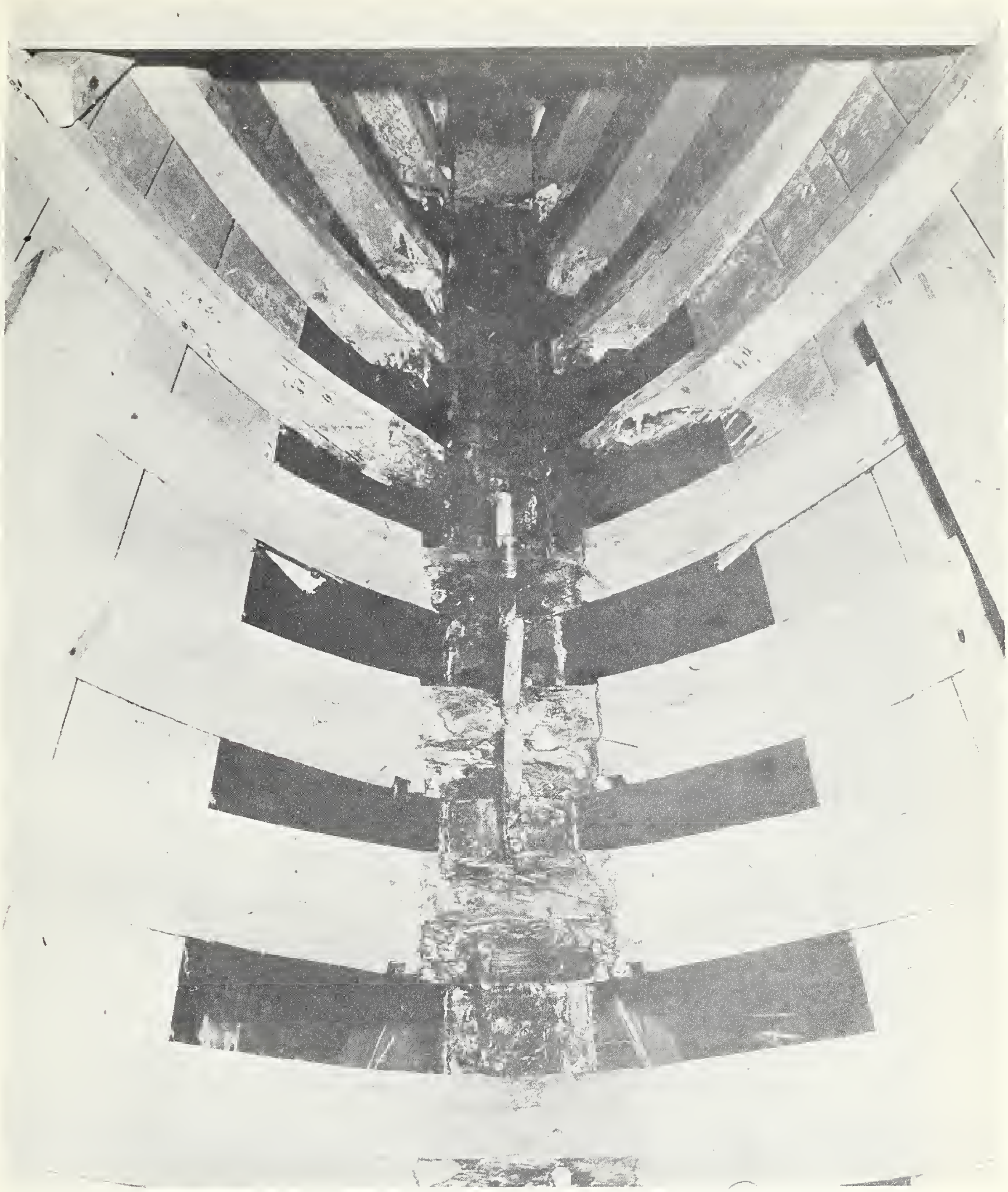

Fig. 10. Boat kept in uncovered storage. Decay apparently entered frames from infected keel assembly.

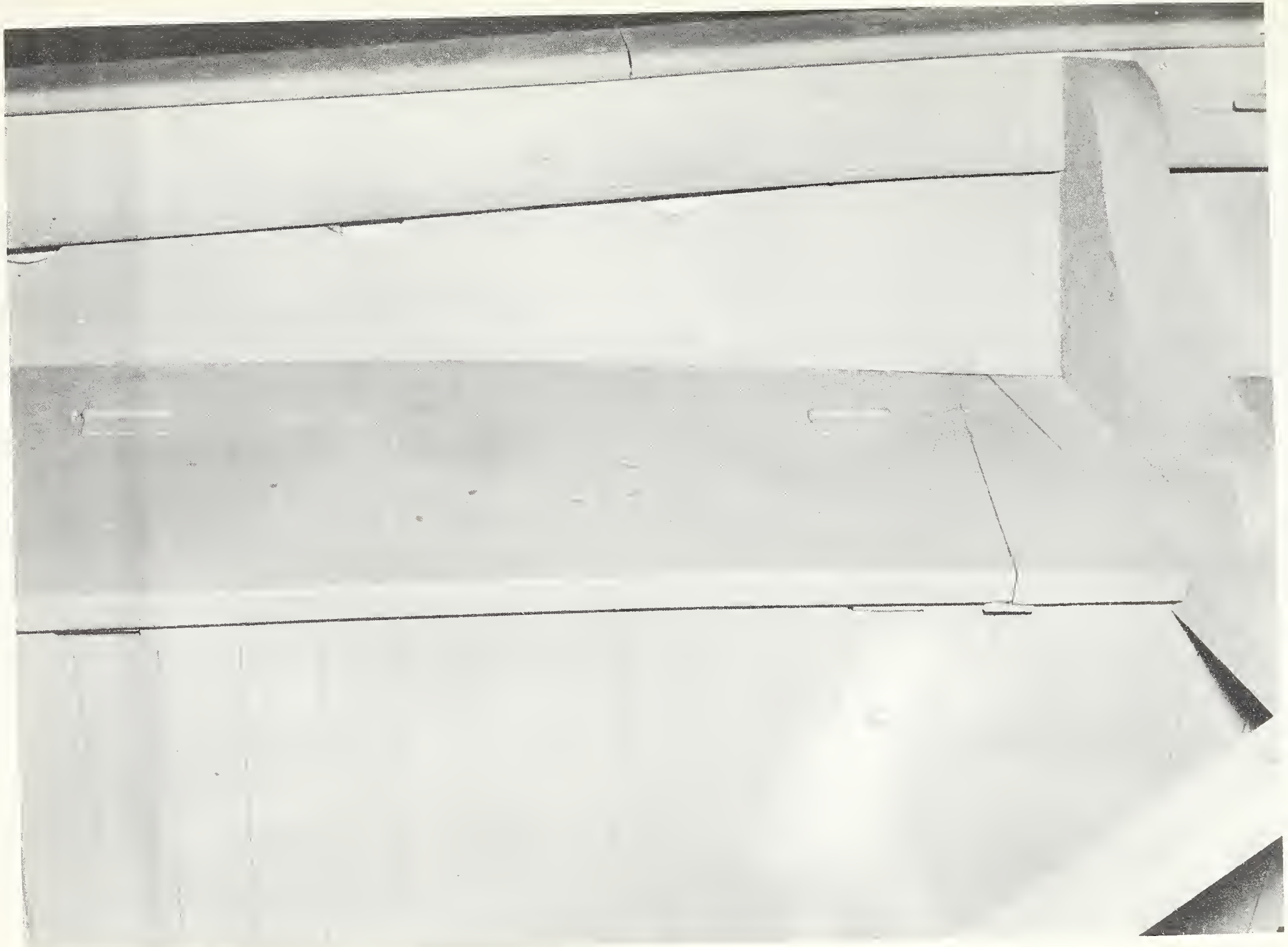

Fig. 11. Interior of Motor Launch 21801 after 4 years under well supported and ventilated canvas cover in Norfolk Naval Shipyard Test 577. Compare with Fig. 12.

Fig. 12. Interior of Motor Launch 220013 after uncovered storage in Norfolk Naval Shipyard Test 577. Compare with Fig. 11.